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Development of a wearable resonator mask for breathing rate monitoring

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Abstract — In medical care, diagnosis and monitoring are crucial stages among the various processes involved in patient care. Sleep apnea is a problem that affects about 25 million Americans, and 80 % of them go untreated because it is not identified. Monitoring has a significant role in making patient treatment decisions. This research aims to produce a wearable resonator mask that can monitor breathing rates. The proposed resonator will use the relative humidity generated during the respiration process. The resonator uses a textile jeans material that is flexible and comfortable and fits on a mask. Testing is carried out in 3 different positions: lying down, sitting, and standing. Based on the measurements that have been carried out, it is known that the proposed resonator produces parameters that meet the requirements. The simulated antenna has an impedance of 50 Ohms and a directional radiation pattern. The measurements of the fabricated resonator show that the antenna works at the Ultra-Wide Band frequency with a main frequency of 3.9 GHz with a bandwidth of 541.6 MHz. Tests with deep breathing samples in 3 positions show different results, where breathing in a lying position produces a lower frequency shift than breathing in an upright position (sitting and standing). It shows that the proposed resonator can monitor respiratory rate well because it can differentiate respiratory rate in different body postures.

Keywords – relative humidity, respiration, ultra-wide band, wearable resonator

I. Introduction

In the medical field, a physician's initial action to gather information about a patient's health involves conducting an examination. The rapid growth of telemedicine devices and remote health services has led to various applications, including telecardiology, specifically designed for diagnosing and treating heart diseases. Telemedicine also plays a crucial role in respiratory monitoring, given that breathing is the most vital sign for assessing the human body's functional aspects and physiological stability [1]. Breathing is a fundamental physiological task in living organisms and is considered an indicator of pathological instability, such as sleep apnea, asthma, pulmonary diseases, and cardiopulmonary arrest. Respiratory monitoring can be used for patient treatment and is vital in newborn monitoring. For example, a sudden decrease in respiratory rate is considered a sign of cardiac arrest and one of the strongest predictors of death.

It is estimated that approximately 1 billion of the world's 7.3 billion people between the ages of 30 and 69 suffer from obstructive sleep apnea (OSA), the most common sleep-disordered breathing disorder. Obesity, a significant risk factor for OSA, is increasing at an alarming rate worldwide. The WHO (World Health Organization) estimates that obesity affected approximately 2 billion adults worldwide in the last five years. Older age is the second most important risk factor for OSA. The infrastructure for OSA diagnosis and treatment must be adapted as the global burden of OSA and related comorbidities is expected to increase [2]. If the time difference between inhalation and exhalation is too long, this may be one of the apnea symptoms [3]. It can also be used to test heart rate variability (HRV), which can be used to identify anxiety while monitoring breathing rate. Voluntary (unconscious) slow breathing of 6 to 9 minutes per minute may facilitate negative emotional processing, whereas stimulated (conscious) slow breathing of 6 to 9 minutes can enhance positive emotions and ultimately increase subjective well-being [4]. Breathing rate monitoring can monitor a patient's disease progression and decide the most beneficial treatment. Breathing rate monitoring has a vital role in determining the actions to be taken by the medical staff during the treatment of the patient [5]. Therefore, new approaches such as electronic health are needed to help the diagnosis process determine the treatment that can be given. Among the latest innovations, the use of sensors is the most developed innovation; in addition to its low-cost production, using sensors that can be used daily increases the convenience and progress of the health field [6]. Among the various types of sensors, one of them is the microstrip antenna, which is widely used in telemedicine with the advantages of a low profile and ease of fabrication. Developing antenna sensors to monitor respiration has been explored in [7], showing similarities to the perception under consideration, monitoring chest expansion during respiration. The antenna's frequency changes when there is a stretching load during chest expansion due to inhaling.

Authors in [7] report an antenna made from metal-glass polymer fiber sewn onto cotton clothing as a prototype for measuring respiratory rate based on chest movement during breathing. This highly flexible sensor can detect the breathing process along with the movement of the volunteer's chest. Sensors sewn into cotton t-shirts can detect breathing processes based on changes in antenna geometry during chest expansion and air volume shifts in the lungs, which result in a significant shift in the antenna's operational frequency. Whereas the percentage of antenna stretching increases, the operational frequency will shift to a higher value. Tests were conducted on two healthy male volunteers with two breathing methods in sitting, standing, and lying body postures.

In [8], a silk fabric-based respiration sensor was designed by successively coating conductive interdigital electrodes and spray coating a graphene oxide (GO) sensing layer sensitive to the surrounding atmosphere, including humidity and temperature. This study explains that the reaction of water molecules with surface functional groups can generate protons on GO nanosheets, further reducing the device's resistance. For optimal sensing performance, the surface density of GO was optimized by measuring the electrical response to the normal breathing of female volunteers. It is known that compared to normal breathing, deep breathing induces a series of much stronger electrical signals with a relatively low frequency. More water vapor can be exhaled during deep respiration, leading to a thick water film on the sensing layer. Thus, the device's resistance is significantly reduced, and strong current signals can be detected. A weak electrical response with a very high frequency is displayed for rapid breathing. The weak signal can be attributed to less moisture in the exhaled air and insufficient removal of the absorbed water layer due to rapid and shallow breathing [8].

Authors in [9] have researched high-performance flexible humidity sensor materials with alternating poly(dopamine)/graphene layers (graphene nanochannels confined poly(dopamine) (GNCP). A humidity sensor based on GNCP nanofilms shows high sensitivity, ultra-fast response, and low hysteresis and is suitable for rapidly detecting moderately sustained humidity changes. The sensor can record highly subtle variations in ambient humidity data caused by talking, singing, breathing, exercising, or even thinking and lying. According to this study, it is also evident that when the relative humidity (RH) is below 35%, the conductivity of GNCP-4 is very low. Notably, a significant increase in conductivity occurs when the relative humidity exceeds 35%. This change may be attributed to a modification in the detection mechanism. The device performs optimally under wet conditions at approximately RH 75% and under dry conditions at around RH 35% [9].

A paper-based humidity sensor that uses the hygroscopic properties of paper (*i.e.*, the ability of paper to absorb water from the environment reversibly) to measure breathing patterns and frequency by detecting changes in humidity caused by inhalation and exhalation cycles into electrical signals was reported [10]. The sensor comprises a paper part with digitally printed graphite electrodes attached to a flexible textile medical mask commonly used in hospitals. The paper sensor digitally prints graphite ink (Ercon Graphite Ink 3456) onto paper with a ballpoint pen and cutter/printer (Graphtec Craft Robo Pro). Since the ionic conductivity of the paper is proportional to the amount of water on the surface of the cellulose fibers, changes in the water content of the paper due to inhalation can be used to monitor breathing. When exhaling, human breath is fully humidified with RH reaching 100 % and therefore increases the amount of water on the sensor and its ionic conductivity. When inhaling, the amount of water on the surface of the cellulose fiber decreases because the surrounding atmosphere almost always has a lower RH than the exhaled air. This change in the amount of absorbed water decreases the ionic conductivity of the sensor [10].

A leather-based electrical sensor that changes humidity during breathing based on changes in the ionic conductivity of the skin was investigated [11]. The sensor is simple, consisting of only a piece of leather and Silver nanowires (AgNWs) interdigital electrodes, using no toxic chemicals. The skin as a porous substrate can provide the device with hygroscopicity and biocompatibility. At the same time, the interdigital electrode is used to improve the utilization of the pool of water vapor from the inhaled and exhaled

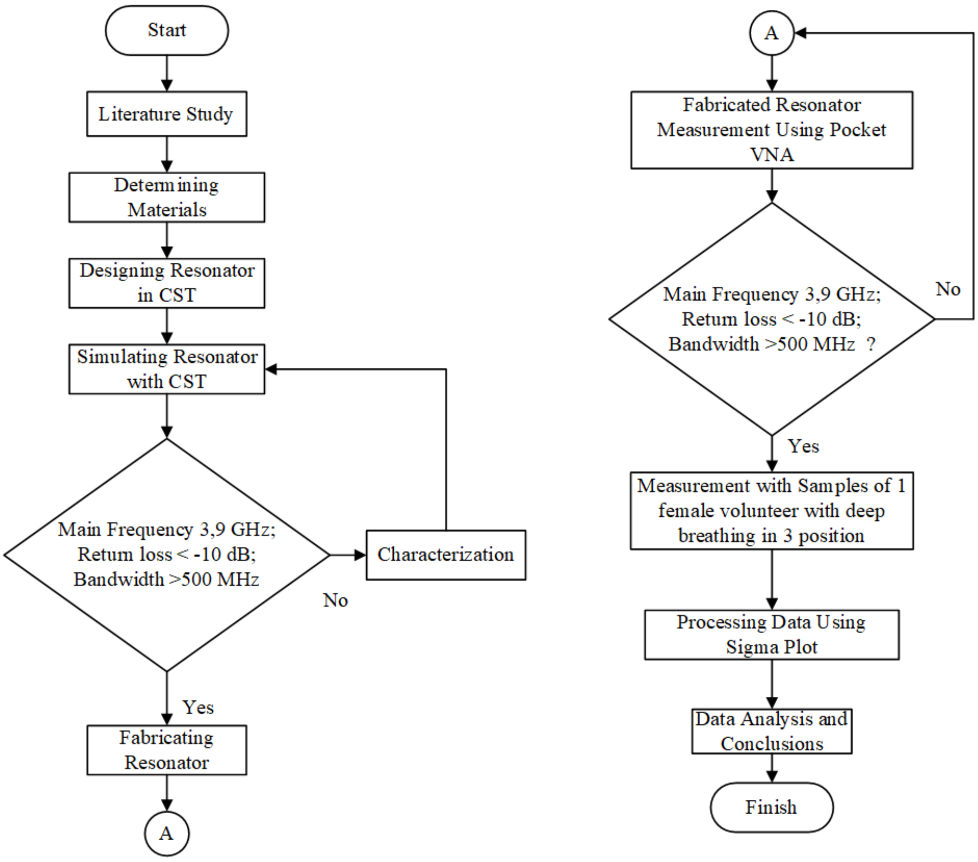


Fig. 1. Research flowchart.

air absorbed by the sensor. During respiratory monitoring when the ambient temperature and humidity conditions were 19.7°C and 30.5 %, respectively, it was found that the humidity inside the mask would change between 81.6 %-86.3 % and the temperature inside would change between 31.8°C and 32.1°C. The breathing depth can be visually observed from the peak height, while the subject's breathing rate can be easily calculated by counting the number of peaks, which is 17 breaths per minute. Mixed apnea, deep breathing patterns, and normal conditions can also be accurately monitored [11].

As far as the authors' best knowledge, limited research uses medical mask sensors to monitor breath rate. No research has reported a wearable textile mask jeans-based resonator for this purpose. The previous study [10] used a paper-based humidity sensor attached to a flexible medical mask. In [11], the authors developed a leather-based electrical sensor for respiratory monitoring. Our paper proposes a wearable textile mask, a jeans-based resonator for monitoring breathing rates through chest expansion. We will monitor the relative humidity in-breath. This research focuses on deep breaths to test the respiratory process, expecting the data obtained to have more significant changes and a higher percentage of relative humidity in deep breathing. The analysis will be performed in three postures: lying down, sitting, and standing. Each test involved four sets, one consisting of 1 inspiration (3s) and one expiration (3s), with a specified time of 6s for 1 set to keep the consistency.

The resonator works within an ultra-wideband frequency range of 3.9 GHz with a directional radiation pattern. The use of Ultra-Wide Band (UWB) can lower power spectral density, resulting in longer battery life [12] and less electromagnetic exposure, making it safer for prolonged use on the body [13] and a directional radiation pattern that optimizes the monitoring process [14]. In addition, this research aims to produce different resonators focusing on the mouth and nose to maximize the breathing monitoring process. The resonator is used to monitor changes in humidity and distinguish between inspiratory and expiratory processes based on the Relative Humidity (RH) in exhaled air. The resonator was then analyzed for accuracy in monitoring respiratory rate based on exhaled humidity through frequency shifting.

II. Research Method

The proposed resonator, known as a wearable resonator mask, will be applied on a mask in direct contact with the body. The research method will be carried out as presented in Fig. 1. The research will begin by increasing the literature study so that we can determine the parameters and materials that will be used for the resonator. The predetermined criteria can be used to design the resonator in the CST software, and then, with the design design, the simulation will be carried out. The parameters that must be achieved include the main frequency at 3.9 GHz, return loss ¡-10dB, and bandwidth ¿500 MHz. The antenna dimensions must be characterized if the specified parameters are not achieved. If the parameters of the simulation results are appropriate, the resonator can be fabricated. The resonator that has been fabricated will have its parameters measured using a pocket VNA to see the suitability of the simulation results with the fabrication results. If the measurement results do not match, it will need to be re-fabricated, but if the measurement results obtained are appropriate, then the sample testing stage can be carried out. Sample testing will be done with the help of 1 female volunteer using the deep breathing method in 3 positions: sitting, standing, and lying down. The test results with samples will then be processed using a sigma plot. The graph produced in the sigma plot can then be analyzed, and conclusions can be drawn.

A. Respiratory

The respiratory system supplies oxygen to the body and removes carbon dioxide as a waste product, divided into two types: internal and external. Breathing, or pulmonary ventilation, increases alveolar pressure due to inspiration, causing the chest to expand and the diaphragm to contract downward as the chest moves. Exhalation relaxes the intercostal and diaphragm muscles, expelling oxygen and carbon dioxide. The primary respiratory centers in the medulla oblongata and pons regulate the rate and depth of breathing. Alveolar ventilation results from the interplay of tidal volume and respiratory rate, influenced by the partial pressures of arterial oxygen and carbon dioxide. The medulla oblongata houses chemoreceptors that monitor carbon dioxide levels in the cerebrospinal fluid [15].

B. Relative Humidity (RH)

One method that can be used in monitoring the breathing rate is by monitoring the relative humidity (RH) produced during inhaling and exhaling. The most common method for measuring RH is utilizing absorptive polymers, which vary their conductive or capacitive characteristics according to how much moisture they absorb from the air [16]. The absorption rate relates to the level of moisture in the air. In addition, highly humidified (89-97% RH) exhaled gas is composed of over 870 other compounds with concentrations ranging from parts per trillion (ppt) to parts per million (ppm) range [17]. In [18], the temperature range of exhaled breath was 31.4-35.4°C in Haifa participants and 31.4-34.8 °C in Paris participants, findings and the relative humidity range of exhaled breath was 65.0-88.6% among Haifa participants and 41.9-91.0% for Paris participants [18]. From these results, we can see changes in relative humidity that we can monitor during inhalation and exhalation. The results of this study help determine the range of T and relative humidity (Relative Humidity) of a person's exhaled breath and its relationship with clinical and environmental parameters such as gender, BMI, and age. Other than that, the present study suggests that posture influences the breathing pattern of healthy individuals at rest. Reducing the rib cage contribution to the tidal volume with aging may encourage the development of strategies to minimize the volume loss of this compartment [19]. Even sitting on a flat surface or in a seat that reclines downward can cause a reduction in abdominal muscles. However, if a more significant respiratory effort is required, the activity in the prone seat may approach that of standing [20]. These aspects must be considered for various measurements in this area.

In this research using the wearable resonator, the parameter that needs to be considered during the breathing process is the percentage of relative humidity, where when the percentage of RH (exhalation) increases, the frequency of the S11 resonator decreases as described by [21]. Previous studies show that as the percentage of RH increases, the dielectric permittivity also increases while the frequency will shift to the left or decrease [22].

When exhaling, human breath is fully humidified (100% RH), which increases the amount of water on the sensor and its ionic conductivity. Since the surrounding atmosphere almost usually has a lower RH than the exhaled air, the amount of water on the mask surface decreases when inhaling. The ionic conductivity of the sensor decreases as the amount of absorbed water changes. As the percentage of RH increases, the resonator's frequency will also change, with a range of 10-40% RH for inhaling conditions and 50- 100% RH for exhaling conditions [23]. Based on other research, it is known that the frequency shift and RH changes can vary from 600 KHz to 900 MHz in the humidity chamber with a change of 6.3 KHz per %RH. Differences in volunteer lung capacity, ambient temperature, and the chosen substrate can induce the frequency shift. This variation arises due to the distinct thermal expansion of different substrates, reflecting their responsiveness to temperature changes [24]. In addition to frequency shifts, two electromagnetic parameters are affected as RH increases: relative permittivity and loss tangent [25]. Permittivity and loss tangent increase with relative humidity, but this phenomenon reverses. It was also shown that time does not affect the dielectric constant value [26].

C. Ultra-Wide Band (UWB)

One of the devices used in telemedicine is the wearable antenna. The use of wearable antennas is widespread because they have the advantage of direct connection to the user, improving the monitoring process and making it more convenient for patients. In addition to convenience, the wearable antenna material is flexible and has high durability [27]. For the use of antennas in telemedicine, it is known that the

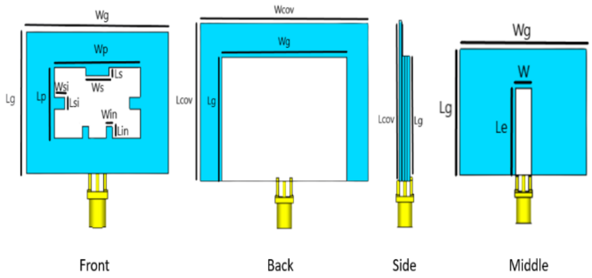


Fig. 2. Wearable resonator design in CST.

ideal telemedicine antenna requires sound transmission and has good flexibility. This condition leads to wearable antenna textile technology that provides comfortable and flexible textile materials that suit the needs of telemedicine. Increase the comfort of using the wearable antenna using flexible and skin-friendly materials such as fabric, denim, cotton, or flannel. The frequency range that will be used in this research is ultra-wideband, which has a frequency range from 3.1-10.6 GHz, which the FCC has allocated (Federal Communication Commission) and has been specified by the Institute of Electrical and Electronics Engineers (IEEE) 802.15.6 standard [28]. Compared to traditional wireless communication systems, UWB technology enables high data rate transmission with low power spectral density. Due to its great potential in wearable communications, UWB technology has been extended to Wireless Body Area Network (WBAN) applications. Lowering the power spectral density results in longer battery life and less electromagnetic exposure for prolonged use on the body [13]. Moreover, UWB antennas feature compact size, low cost, and wide bandwidth [29].

D. Materials

In the design process, parametric study and optimization are needed to obtain the desired parameter. This resonator was designed using CST (Computer Simulation Technology) Microwave Studio Software. The material to be used is Jeans Fabric ($\varepsilon r = 2.65$) with a thickness of 1mm and shield ($\varepsilon r = 6.67e + 5$), which is a lossy metal as a conductor. The fabricated resonator will be sewn into the mask to be used as a wearable textile resonator. A pocket VNA will be used to monitor changes in the desired parameters for testing.

E. Wearable Resonator Design

Fig. 2 shows the design of an ultra-wideband flexible resonator composed of 3 layers of jeans as a substrate; the first layer shield is attached behind the substrate as a ground, and the second layer shield is attached in front of the substrate as a resonator patch and accompanied using a cover made of jeans to protect the resonator patch so that the accuracy of the resonator is kept maintained. The use of 3 layers substrate aims to increase the resonator's bandwidth. The coupling method used in this resonator is the proximity coupled method, where the feedline will be placed between 2 substrates. The proposed resonator uses a proximity-coupled feeding technique. This feed technology has many advantages, such as wider bandwidth and low spurious radiation. Proximity-coupled feeding techniques may also improve the gain and efficiency of the proposed antenna [30].

Table 1. Dimension of Simulated Resonator

Components	**Size (mm)**
Lg (Ground Height)	36
Wg (Ground Width)	48
Lp (Patch Height)	18.04
Wp (Patch Width)	29
Le (Feedline Height)	25
W (Feedline Width)	6
Lin (Bottom slot Height)	3
Win (Bottom slot Width)	2
LS (Top slot Height)	2
Ws (Top slot Width)	8

The dimension of the resonator will be presented in Table 1. An SMA (SubMiniature Version A) port will be attached to the user's mask.

Fig. 3 shows the wearable textile jeans-based resonator mask for breath rate monitoring. This prototyping will be done after obtaining simulation results matching the desired parameters. The selected material will then be cut to match the dimensions of the antenna according to the final resonator design after characterization. The material that has been cut will then be arranged with one patch layer placed on the first jeans layer, one feedline layer placed on the second jeans layer, and one ground layer placed on the third jeans layer. Silver conductive thread is used to connect the patch and the feedline. It will be tested using a multimeter to test the connectivity between the two components. If the connectivity between the two has been tested, the three layers of jeans can be arranged into one unit by sewing the edges of the substrate using non-conductive thread. After the resonator is arranged, the SMA port can be soldered. Testing can be carried out using a pocket VNA connected to the resonator port to test whether the fabricated resonator parameters match the parameters of the simulation results. It is essential to position the resonator close to the monitoring source to optimize the monitoring of relative humidity (RH) changes, ensuring its operation remains in proximity to the human body [31]. The resonator is fitted to the medical mask by sewing the edges of the resonator into the mask. Velcro is used to cover the resonator and put directly inside the mask. Thus, the wearable textile resonator mask is ready.

F. Measurement Setup

Fig. 4 shows the measurement setup of a wearable textile resonator mask for breath rate monitoring. One female volunteer is used as our object test. The tests will vary on the breathing position and level of breathing depth. The positions to be tested are sitting, standing, and lying down. The breathing depth is divided into Shallow Breathing (SB) or relaxed breathing

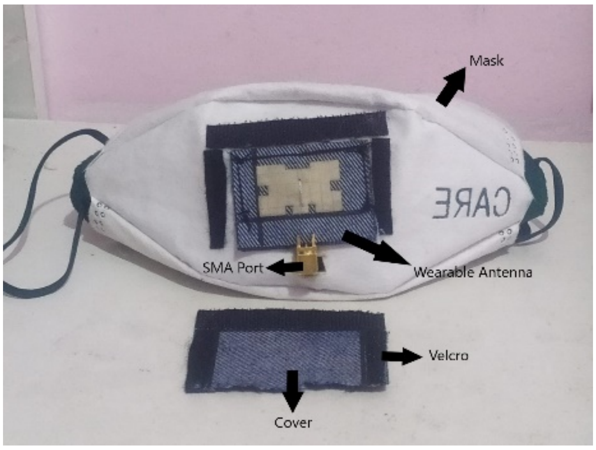


Fig. 3. Wearable textile jeans-based resonator mask.

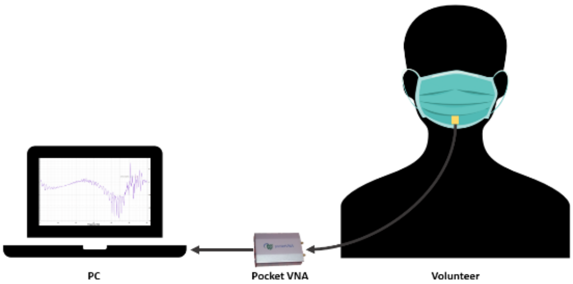


Fig. 4. Prototype of measurement setup.

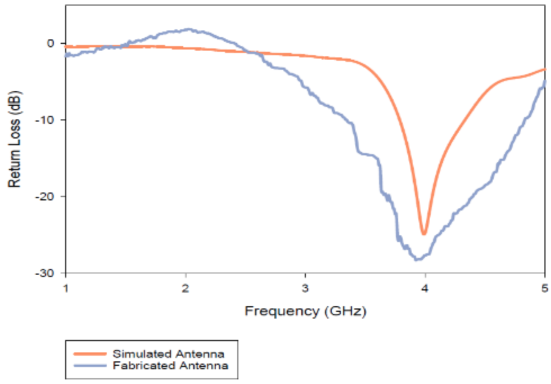


Fig. 5. Comparison of simulated and measured resonator.

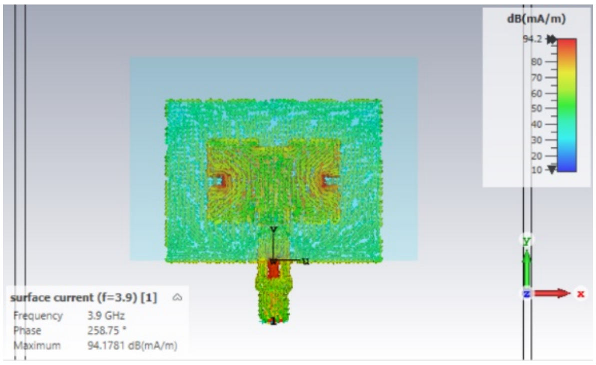


Fig. 6. Surface current of proposed resonator.

and Deep Breathing (DB), where the volunteer will inhale and exhale as deeply as possible. However, for this test, only DB will be tested. The breathing time range will be set to maintain the test's consistency and monitored throughout the process using a stopwatch. For DB, the breathing period for exhaling-inhaling is 3s. Sampling will be done in 1 set for the exhaling-inhaling deep breathing process four times at three breathing positions.

III. Result

The resonator works in the range of 3.4 GHz to 4.4 GHz with a center point of 3.9 GHz. Fig. 5 shows that the main frequency of the resonator is obtained at 3.992 GHz with an S11 of -24.91 dB with a bandwidth of 541.6 MHz (3.8 GHz to 4.3 GHz). The fabricated resonator produces parameters that are close to the simulation results. In contrast, differences in parameter results can be caused by differences in the materials' characteristics or human error during the process of making wearable resonators.

Fig. 6 shows the surface current of the resonator at 3.9 GHz. The highest current flows into the slot cutting at the edge of a resonator with a maximum current of 94.2ma/m.

A directional radiation pattern is shown in Fig. 7. It is vital to measure the humidity with a gain of 3.22 dBi.

Fig. 8 - Fig. 10 are the measured results of the volunteers' deep breathing, exhaling, and inhaling processes, lasting 3 seconds in each process. One wave represents one set of one inhalation and one exhalation. Therefore, the four waves in the figure result from four groups of inhalation and exhalation processes. One wave lasts 6 seconds, and four waves last 24 seconds. Fig. 7, during the respiration process, the main frequency shifts by 400-500 MHz, with the lowest point at 4.3530 GHz and the highest point at 4.8339 GHz in the laying down position. Fig. 8 shows the main frequency shift of 400-700 MHz during deep breathing for the sitting position, with the lowest point at 4.0404 GHz and the highest point at 4.7617 GHz. In the standing position test in Fig. 9, the main frequency shifts by 500-700 MHz, with the lowest point at 3.3191 GHz and the highest point at 4.0885 GHz. There is a difference in the frequency shift range of the three positions tested. The laying down position test has the smallest range compared to the other two tests. This result can be caused by different breathing

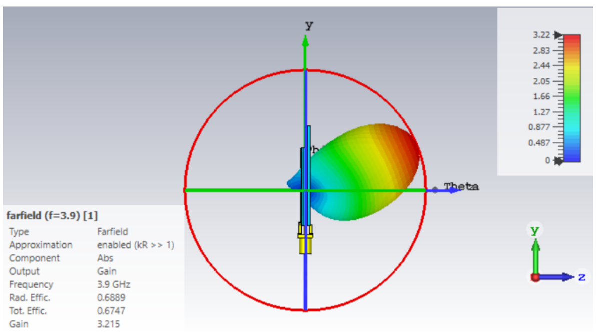


Fig. 7. Radiation pattern of proposed resonator.

volumes, wherein the upright body position (sitting and standing) allows breathing with more volume. On the other hand, the laying down position has a weight-bearing so that there is limited space for the lungs to expand fully, which results in the volume produced during the exhaling-inhaling process being less than the other tests, which shows that differences in posture can produce significant differences in the RH produced during the breathing process [32].

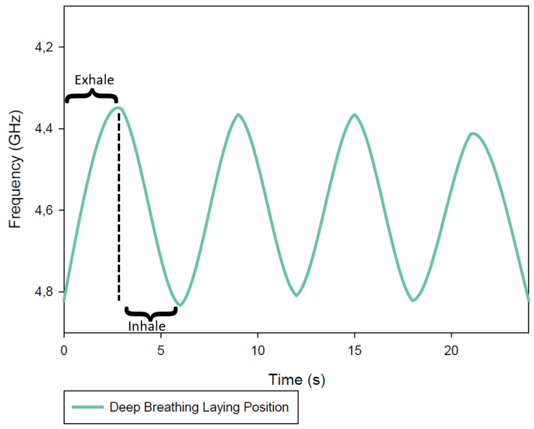


Fig. 8. Measurement of deep breathing in laying down position.

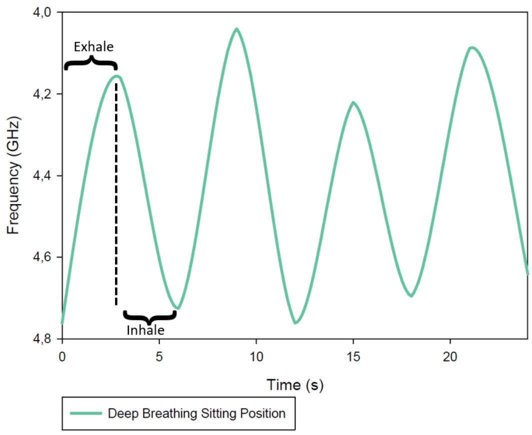


Fig. 9. Measurement of deep breathing in sitting position.

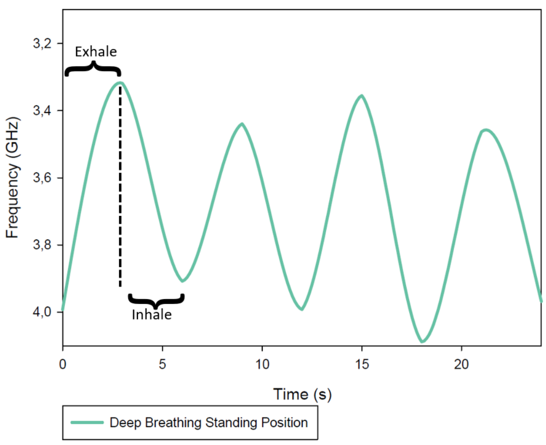


Fig. 10. Measurement of deep breathing in standing position.

The analysis was carried out based on previous research [23] that changes in the relative humidity percentage in exhaled air range from 10 to 40% for inhalation conditions and from 50 to 100% for exhalation conditions. Table 2 shows that the resulting RH is reversible when the wearable resonator does not detect the humidity; the frequency will return to nearly its starting point [26]. Based on the relationship that, as the frequency decreases, the percentage of RH will increase [21]. However, the change in frequency to the percentage of RH is not constant or produces a fixed value in each test set. There is a difference in the final frequency of each running process. A pattern shows that at one point, the exhaling frequency will decrease deeper than the previous set. That could have happened because the humidity generated by the previous set did not entirely disappear from the mask, resulting in the detected RH greater than the previous set. This analysis can be proved because the obtained inhaling data does not have the same value between tests. The frequency value for each inhaling decreases over time.

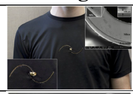
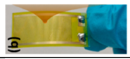
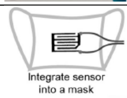
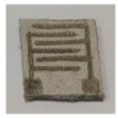
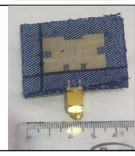
Table 2. Frequency Comparison for Each Position

Time (s)	Process	Frequency (GHz)		
		Laying down	Sitting	Standing
3	Exhaling	4.35	4.16	3.32
6	Inhaling	4.83	4.73	3.91
9	Exhaling	4.37	4.04	3.44
12	Inhaling	4.81	4.76	3.99
15	Exhaling	4.37	4.22	3.36
18	Inhaling	4.82	4.70	4.08
21	Exhaling	4.41	4.09	3.46
24	Inhaling	4.82	4.64	3.97

Based on the tests, the proposed resonator can be used as a sensor to monitor the breath rate. This result was confirmed by testing the wearable resonator during inhalation-exhalation at three breathing positions by frequency shift occurring in given humidity. In addition, the proposed resonator has a directional radiation pattern so that it can be focused on a single point towards the nose; thus, changes in the surroundings will not affect the performance of the wearable resonator. A comparison between the proposed resonator and the previous research is shown in Table 3. Three positions are evaluated with this resonator and give a significant contribution.

This outcome aligns with the hypothesis suggesting that variations in body posture during the breathing process influence the generated amount of relative humidity (RH). The test results also support this outcome, indicating discernible differences in frequency shifts among various test positions. Despite the differences in the range of frequency shifts, the resonator continues to function effectively, reliably monitoring changes in RH during the breathing process. The proposed resonator functions well at the specified working frequency, where it can adequately detect the respiratory rate based on changes in the breath's humidity level. Based on a comparison between the journal [7], which has an ISM main frequency, and the proposed resonator in this research, we get the same measurement results where both show that monitoring of respiratory rate

Table 3. Comparison with Previous Studies

References	Material	Sensing	Parameters	Posture	Gain	Bandwidth	Design
[7]	Metal-glass polymer fiber	Chest Movement	Frequency (2.45 GHz)	Sitting, Standing, and Laying down	3.41 dBi	N.A	
[8]	Silk Fabric	RH	Current	Sitting	N.A	N.A	
[9]	Polyimide	RH	Current	Sitting and Standing	N.A	N.A	
[10]	Paper	RH	Conductivity	Sitting	N.A	N.A	
[11]	Leather	RH	Current	Sitting	N.A	N.A	
This resonator	Jeans	RH	Frequency	Sitting, Standing, and Laying down	3.22 dBi	541.6 MHz	

can be done by observing the frequency shift and the test results show that the respiratory rate in the laying down position has lower respiratory volume compared to breathing with an upright body position. Based on this comparison, the author concludes that the proposed resonator can work well at a frequency of 3.9 GHz and the performance of reference [7], which uses a frequency of 2.45 GHz.

IV. Conclusion

The authors have successfully developed a wearable textile jeans-based resonator mask for breath rate monitoring. The resonator operates well in monitoring changes in the RH percentage, which indicates the inhaling-exhaling process during the breathing process. The tested resonator uses jeans as a flexible and durable substrate that is comfortable to use. A directional radiation pattern on the resonator maximizes data collection during testing. Three positions, lying down, sitting, and standing, are evaluated to ensure the resonator works at the desired parameter and to prove that there is a difference in the percentage of RH produced from each position based on the difference in the frequency range produced.

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